Virtual reality. Because of this new approach to visualization, the way Americans work and play in the year 2000 will be very different from the way they used tools and toys 50 years ago. With this one leap in imagination from the computer age, Americans are now able to experience and actually interact with events and environments that are far away, or even nonexistent.

Advanced technology offers much in this area, allowing, for example, a businessman in California to demonstrate his product to people in New York and note his audiences' facial expressions in real time. It can allow business people to advertise products in three dimensions right on a computer screen or carry their computer screens rolled up underneath their arms like newspapers.

Today's market. Used by everyone from children to chief executive officers, communications and multimedia technologies offer diverse and widespread markets. For example, the percentage of household income spent on telecommunications services is expected to grow significantly from its current 2.1 percent[1] as expanding services include offerings such as multimedia entertainment. The world market for fiber-optic cable is expected to double by 2000; the U. S. share was roughly $3.1 billion in 1993.[2] TV video games accounted for about $3.8 billion of the almost $16.4 billion toy industry in 1994.[3]

Tomorrow's opportunity. BMDO has funded numerous photonics, electronics, computer-related, and even power technologies for tracking and destroying ballistic missiles that may lend themselves to the communications and multimedia industries. The following section highlights seven of these technologies and the companies that are commercializing them.

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[1] *Industry Surveys*, Standard & Poor's, June 1994, p. T-15.

[2] *Industry Surveys*, Standard & Poor's, June 2, 1994, p. T-44.

[3] *Industry Surveys*, Standard & Poor's, April 6, 1995, p. L-59.

COMMUNICATIONS AND MULTIMEDIA

BMDO-Funded Power R&D Captures Market For Cellular Communications

When cellular telephones were introduced in the early 1980s, their financial success came as no surprise; the surprise was in just *how* successful they became. Originally targeting the rich, famous, and very very busy, cellular telephones overcame the obstacles of a then sluggish economy, topping 10 million users in their first decade—figures not projected until the turn of the century.[4]

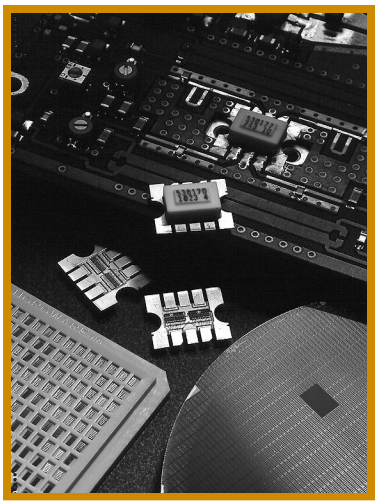
Spectrian primarily sells its products to large cellular equipment manufacturers.

Capitalizing on this boom in wireless communications, Spectrian Corporation (Mountain View, CA), has undergone the transition from military contractor to commercial supplier, with the help of power technology developed for BMDO's Neutral Particle Beam (NPB) program. Now a major supplier of radio frequency (RF) amplification systems, Spectrian sells its products primarily to large cellular equipment manufacturers, such as Northern Telecom, Ericsson, AT&T Corporation, Motorola, and QUALCOMM.

USING BMDO-FUNDED R&D FOR ITS CELLULAR COMMUNICATIONS PRODUCTS, SPECTRIAN IS CAPITALIZING ON THE BOOM IN WIRELESS COMMUNICATIONS.

Spectrian's systems are being used in the base stations of cellular systems; broadband, personal communication services; personal communication networks; and fixed wireless access networks. In 1993 (the most recent year for which data are available), the company accounted for about 15 percent of the quarter-billion-dollar-plus market for cellular base stations. It held an initial public offering in August 1994.

The company's systems can support an array of analog and digital transmission standards and can provide the power levels needed by the base stations that cover both large geographic regions (macrocells) and by those that cover smaller regions (microcells). The main selling point of the company's amplifiers is linearity. Linearity is a measure of the degree to which amplified signals remain within their prescribed band of the electromagnetic spectrum with low distortion or interference from adjacent channels. With greater linear power amplification, base stations can transmit more signals at a given frequency range. This gain in spectrum efficiency means lower capital costs per subscriber and clearer, higher quality transmission.



Spectrian's power transistors and amplifiers, shown above in various stages of production and packaging, provide better linearity; better linearity allows base stations to transmit more signals at a given frequency range, translating to clearer, higher quality transmission.

About The Technology

For the BMDO NPB program, Spectrian designed and manufactured lightweight, reliable, high-power amplifiers for compact particle accelerators. In these accelerators, the amplifiers produce the RF signals used to accelerate and bunch particle beams.

During this work, Spectrian helped spur dramatic progress in the power output of a single RF transistor at specific frequency ranges. A single device developed for this program produced up to 250 watts at 425 megahertz (MHz)—five times better than previously possible. Spectrian's research also cut the cost of solid-state power transistors by a factor of 10. The NPB program later funded the company to build high-power transistors that operate at 850 and 1,700 MHz. The high-peak-power requirements of all these transistors played a big role in improving the linearity of the devices Spectrian sells today.

Building on this technology, Spectrian has developed a technology for producing multicarrier power amplifiers; that is, amplifiers that can dynamically reallocate frequencies so that base stations can follow automotive traffic from cell to cell. The typical multicarrier power amplifier works by combining from 10 to 19 single-carrier power amplifiers in one unit.

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[4] *Industry Surveys*, Standard and Poor's, April 1, 1993, p. T-33.

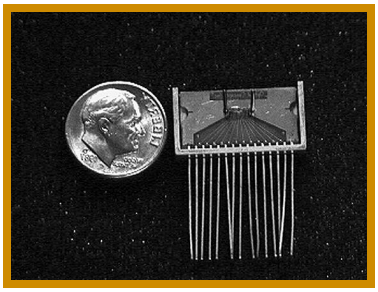
Joint Venture May Break Traffic Bottlenecks On Information Highway

As a result of a recent joint venture, Optical Concepts, Inc. (Lompoc, CA), is entering the commercial marketplace with its vertical cavity surface emitting lasers, or VCSELs (rhymes with pixels)—a move that may meet the growing needs of the telecommunication market. The company's "lasers on a chip" can widen the information highway by allowing more digital traffic to travel over fiber-optic cables while making communications systems simpler and cheaper to manufacture and install. BMDO originally funded this research through an SBIR contract.

By placing thousands of tiny lasers on a single 1-inch chip, researchers at Optical Concepts have developed devices that may reduce the hardware needed to transmit information over fiber-optic cables. These devices will also allow multiple signals to travel simultaneously down a cable, making interactive information services, such as video phones, business conferencing, and distance learning, more affordable and free of bottlenecks. In addition, the company's device has better beam quality than current technology.

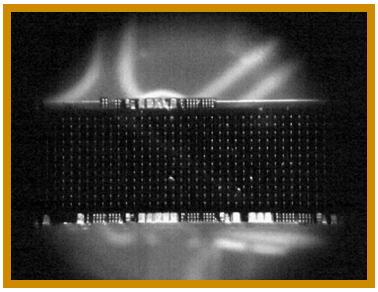
THIS BMDO-FUNDED DEVICE CAN WIDEN THE INFORMATION HIGHWAY BY SIMPLIFYING COMMUNICATIONS SYSTEMS AND MAKING THEM CHEAPER TO MANUFACTURE.

Packaging has been a major cost concern in the traditional processes for manufacturing laser diodes. But since VCSEL chips are smaller and much simpler than conventional diode laser technology, they cost much less to package.



To commercialize its product, Optical Concepts recently signed a marketing agreement with AMP, Inc. (Harrisburg, PA), a Fortune 200 company with a broad business background in electronic packaging and optoelectronics. AMP will market Optical Concepts' VCSEL products and make an equity investment in the company. The capital raised from this deal will allow Optical Concepts to establish the integrated manufacturing facility needed to begin mass-producing VCSEL products.

In the near term, VCSELs can be used in short-distance optical communications such as local area networks. But Optical Concepts is also looking at longer term VCSEL solutions for telecommunications, an area previously plagued with problems associated with limited wavelengths. Signals from earlier VCSELs, which could only operate at near-infrared wavelengths (around 980 nanometers), weakened too quickly for long-distance communications. Optical Concepts recently demonstrated and submitted a patent on the first room-temperature VCSELs operating at 1,550 nanometers—the ideal wavelength for long-haul communications. The company is integrating the lasers in an array specially designed for communications systems.



Optical Concepts has also produced VCSELs that emit blue light. These short-wavelength lasers may be the key to new types of high-density storage devices, since optical storage density increases as wavelength decreases. Blue VCSELs also open the door to applications in high-definition displays and laser printers. Other possible VCSEL uses include medical lasers and spectroscopic imaging.

Above: VCSELs are roughly 20 to 50 times smaller than edge-emitting diode lasers. Pictured above is a VCSEL package produced by Optical Concepts.

Below: VCSELs look like miniature skyscrapers in micrographic images and can be easily stacked side-by-side in one- and two-dimensional arrays.

About The Technology

VCSELs emit laser beams perpendicular to their face surface (hence their name), unlike other diode lasers, which emit light from their edges. At about 10 microns in diameter, they are roughly 20 to 50 times smaller than edge-emitting diode lasers. They look like miniature skyscrapers in micrographic images and can be easily stacked side-by-side in one- and two-dimensional arrays. Researchers have demonstrated better than 90 percent coupling efficiency between VCSELs and fiber optics. Optical Concepts' VCSELs also double the electrical-to-optical efficiency of most competing technology, demonstrating conversion efficiencies of more than 50 percent.

New Amplifiers Improve Fiber Optics

With 60 million kilometers of cable installed worldwide, fiber optics has become an industry standard, forming the backbone of a $5.7 billion global market.[5] Compared with other transmission media, such as copper telephone wires, fiber optics allows telecommunications companies to move more information at a lower cost. And unlike information sent over copper wires, optical digital information can be sent with little worry about the signal scrambling from electromagnetic interference.

But to transfer information over long distances, fiber-optic cables require rather costly electronic regenerators about every 30 to 60 kilometers to boost the signals they carry. Industry could save substantially with low-cost amplifiers to boost signals over longer distances, thereby reducing the number of needed amplifiers.

Responding to the call for better transmission, Optigain, Inc. (Peace Dale, RI), is launching four to eight different product lines in active fiber devices, some of which are available now. The company's products are based on BMDO SBIR-funded R&D for erbium-doped fiber amplifiers (EDFAs) and other rare-earth-doped devices. EDFAs can be retrofitted onto existing systems, allowing the industry to upgrade fiber-optic systems quickly and affordably while increasing the distance between amplifiers to about 70 kilometers.

OPTIGAIN'S TECHNOLOGY CAN ALLOW INDUSTRY TO UPGRADE FIBER-OPTIC SYSTEMS QUICKLY AND AFFORDABLY.

In addition, when used with many wavelength division multiplex (WDM) channels, EDFAs can increase bandwidth, allowing 2 to 10 times more information to flow through the communications system. The combination is ideal for broadband communications to support two-way voice, video, and data conveyance.

In the future, Optigain hopes to revolutionize the optoelectronics industry. The company envisions EDFAs, WDMs, and other fiber-optic devices packaged together, in a new technology called integrated fiber circuitry, or IFC. An IFC will be composed of active and passive fiber devices that can be easily interconnected and fabricated using a range of available and developing optical materials. IFCs will yield complex all-optical functions in telecommunications, cable TV, sensing, instrumentation, and optical storage.

Optigain originally developed a low-cost EDFA for BMDO to improve communications capabilities. The BMDO SBIR contract developed EDFAs in the 1,550 nanometer range—the bandwidth for telecommunications that allows data to travel farthest. This research has also contributed to Optigain's efforts in developing lasers and superfluorescent sources. The company has received funding from the Navy and the Air Force in related areas.

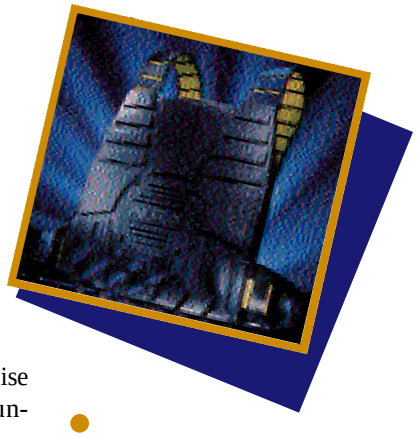
Pictured above is Optigain's doped fiber amplifier for the 1,550 nanometer band; it has high output power capabilities of 40 mW.

About The Technology

Optigain, Inc., has developed an optical fiber amplifier used at points of loss in optical systems to intensify the arriving signal. This technology is an example of an active fiber device (AFD) that has broad applications in fiber optics and photonics. In AFDs, silica or heavy metal fluoride glass hosts are doped with one of several rare-earth elements, rendering the fiber optically active when energized with a pumping laser. Rare earths are metals of the lanthanide series of the periodic table (57 through 71). AFDs doped with rare earths such as praseodymium, terbium, and thulium are compatible with the laser propagation modes of current passive fiber devices. By amplifying the fiber-optic beams directly, eliminating an electrical signal conversion step, AFDs reduce power loss and noise in optical systems.

[5] Optical Amplifiers Transform Lightwave Communications…*Photonics Spectra*, January 1995, p. 115.

BMDO-Funded R&D Finds Markets In Amusements, Transportation



The Interactor™ is a vest that, when worn while playing video games, allows players to feel acoustic sensations related to what is happening onscreen.

While attention on multimedia entertainment today seems to be focused on its visual aspects, Aura Systems (El Segundo, CA) is bringing more excitement to the audio side. The company's BMDO-funded high-force actuator (HFA) has been incorporated into products that help players "feel" the sounds.

The company's BMDO-funded electromagnetic R&D can result in acoustic energy or cancel noise and vibration; its uses range from improvements in aircraft, cars, and helicopters to more fun-and-games applications, such as interactive video games and amusement park rides.

Aura has made great strides in commercializing this research, with the Interactor™, a vest that allows video game players to feel acoustic sensations related to what is happening onscreen. The Interactor™ is available in the United States, and Aura has agreements to sell the product in more than 14 foreign countries. The company also won an Innovations '94 Design and Engineering Award from the Electronics Industry Association for the product's development.

AURA SYSTEMS HAS AGREEMENTS TO SELL ITS AWARD-WINNING INTERACTOR™ IN MORE THAN 14 FOREIGN COUNTRIES.

The same technology can add the sense of feeling to theater seat cushions and amusement park rides. HFA technology has already been installed in the Las Vegas Luxor Hotel's Theater of Time. Aura is also involved in a joint venture with InterGroup Corporation to design, assemble, market, and sell entertainment simulator rides. And, on a more musical note, the company has used its technological breakthroughs to make AuraSound™ audio speakers. These speakers have one-sixth the harmonic distortion of conventional speakers and produce no perceptible magnetic interference.

The HFA technology also has some important transportation applications, replacing camshafts and associated valve train components to open and close engine valves. Called electromagnetic valve actuators (EVAs), Aura's technology is expected to increase horsepower and fuel efficiency while lowering emissions compared with standard valve train engines. EVA engines can also use various types of fuels. Aura is testing a 2.3 liter EVA engine and has announced deals with Yamaha, Perkins, and Cummins (some of the world's largest diesel manufacturers) to demonstrate its innovation.

Aura's HFAs can also be used to cancel vibration in helicopters and elevators, as well as in buildings and bridges that are vulnerable to earthquakes or other stress.

About The Technology

Aura's patented HFA is an electromagnetic actuator that can operate at acoustic frequencies (like a loud speaker coil) but produces greater force on impulse than conventional devices. BMDO used the technology for the lightweight exoatmospheric projectile program. HFAs can provide the high forces and long strokes of hydraulic or pneumatic actuators at the speed and precision of voice coil actuators. High-energy permanent magnets are arranged to focus nearly all of their energy into useful work, using nearly 90 percent of the available magnetic energy. Standard voice coil actuators use only about 40 percent. And because the HFAs are completely electromagnetic, no petroleum-based or organic hydraulic fluids are required. This fact, coupled with its shielded design that prevents electromagnetic radiation emissions, makes Aura's HFA technology as environmentally sound as it is commercially attractive.

Flexible Light-Emitting Diodes Result In Licensing Agreement

Sports fans in some seats at stadiums and ballparks may have trouble seeing the electronic scoreboard because of its angle. The lights of the display are not visible when viewed too far from the side. But soon, every fan will have a good view of the scoreboard, because the display will be able to be curved, thanks to Uniax Corporation's (Santa Barbara, CA) bend-like-rubber light-emitting diodes (LEDs).

Because scoreboard displays use thousands of interconnected LEDs with stiff metal electrodes, they must be mounted on flat surfaces. By replacing these electrodes with a processible conducting polymer material, Uniax can manufacture thin sheets of LEDs that can be curled or bent in half without disrupting their light-emitting properties. These highly flexible LED sheets would allow displays to be curved or wrapped around objects. In addition, the new LEDs glow about twice as brightly as a television screen.

This eight-segment polymer electroluminescent display prototype can be flexed during operation and emits bright orange light at 5 volts dc.

Uses for flexible LEDs go far beyond better electronic scoreboards. For example, they may be used to display icons and text in personal telecommunications products, such as pagers, while also reducing power requirements and weight. Eventually they can be used for presentations, allowing business people to roll up high-definition, full-color television displays and carry them under their arm.

UNIAX IS COMMERCIALIZING A BMDO-FUNDED TECHNOLOGY THAT, AMONG OTHER CAPABILITIES, WILL ALLOW DISPLAYS TO CURVE AROUND OBJECTS.

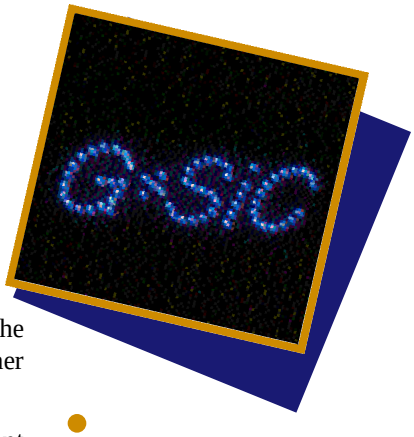
Other applications include windows that automatically control how much sunlight enters a room. LEDs could also be used in transdermal patches to release drug doses on a schedule rather than continuously, like today's patches.

Uniax has licensed to Neste Chemicals (Porvoo, Finland) the core technology, a conducting polymer called polyaniline (PANI), for non-LED applications. PANI is environmentally stable, will not lose its conductivity with typical use, and can be mixed with traditional bulk polymers to improve conductivity. Scaling up to industrial production, Neste Chemicals is using PANI to develop products such as electro-active plastics, coatings, and adhesives and has already demonstrated PANI articles through melt and solution processes.

About The Technology

Previous attempts to make PANI resulted in unmanageable, gelatin-like solutions that could not be processed using traditional melt and solution techniques. Under BMDO SBIR contracts, Uniax Corporation developed cost-effective processing technology that will make it easier to produce PANI in high volumes. By using simple doping techniques, Uniax researchers have been able to increase PANI's processibility. A surface active molecule simultaneously protonates and bonds to PANI polymer chains. As a result, PANI and a variety of polyblends made from PANI become electrically conductive and soluble in several common non-polar or weakly polar organic solvents.

Intellectual Technology Transfer Leads To International Sales



Cree is the largest U.S. producer of blue LEDs, which can be used for displays, as shown above.

In 1987, five graduate students at North Carolina State University realized that their expertise in silicon carbide electronics put them in a unique position to bring a technology with great potential in displays, communications, and high-temperature electronics to the marketplace. The problem was finding the best vehicle for commercialization. Instead of scattering across the country to new positions in industry and academia, these students decided to remain together and form a small company. This way, their concentration of expertise would not break up.

After borrowing money on credit cards, taking out second mortgages, and scraping up investment capital from family and friends, the students formed Cree Research, Inc. (Durham, NC). Two years later, they had their first product on the market—a light-emitting diode (LED) that produces blue light. Such diodes provide the missing ingredient in products designed to display, recognize, or replicate the full color spectrum, including outdoor displays, color recognition sensors, color slide and film scanners, and digital color photographic printers.

CREE RESEARCH'S SUCCESS ILLUSTRATES ONE OF THE GREAT VALUES OF UNIVERSITY-BASED R&D: LESSONS LEARNED BY STUDENTS THROUGH DEFENSE RESEARCH CAN CREATE NEW COMMERCIAL PRODUCTS.

Some of the early North Carolina State research included BMDO-funded programs in nitride-based semiconductors, materials with properties very similar to silicon carbide. Later, when the students formed Cree, BMDO became one of the company's biggest supporters. The SBIR program awarded the company three R&D contracts and the IS&T program awarded a fourth.

Today, more than 2 years after a 1993 initial public offering, Cree is the world's only significant commercial manufacturer of silicon carbide wafers and the largest U.S. producer of blue LEDs. It sells more than $4 million of these two products annually in the United States, Europe, China, Japan, Korea, and Taiwan. As for the future, Cree recently introduced a brighter blue LED that should greatly expand the technology's market potential, and it has formed several strategic alliances to market its blue LEDs better and to develop new silicon carbide products.

Such success clearly shows one of the great values of university-based research: Students take the lessons they learn with them when they graduate, lessons that sometimes form the basis for new products or help introduce new efficiencies to a business. The full impact of the process, called “intellectual technology transfer,” is almost impossible to quantify, since students rarely stay together as they did in the case of Cree.

About The Technology

As a semiconductor material, silicon carbide (SiC) has several properties that make it attractive for devices that provide blue light emission, ultraviolet sensing, nonvolatile computer memory, and high-power, high-frequency, high-temperature operation.

Silicon carbide's most important property is its wide energy bandgap—a property of semiconductors that determines the amount of energy needed to make the material carry current. This wide bandgap (2.8 electron volts) means that heat and other external influences do not readily disrupt the performance of SiC microelectronics, so SiC devices can operate at higher temperatures and higher radiation levels than devices based on silicon and gallium arsenide. SiC can also operate at higher power levels and can emit blue light. Other desirable properties include a high maximum electron velocity (SiC devices can operate at high frequencies), a high thermal conductivity (SiC devices can easily dissipate excess heat), and a high breakdown electric field (SiC devices can operate at high voltage levels).

Several technical barriers to making defect-free, single-crystal SiC wafers had prevented their widespread use. Over the years, Cree has steadily lowered the defect density and cost of its SiC wafers, making the material commercially viable for some uses and nearly so for many others.

Commercialization Of New LEDs May Be True Blue (And Green)

Light-emitting diodes (LEDs) have been available for more than 20 years and are used in everything from electronics indicator lights to sensor devices. But the early devices were limited to the red portion of the visible spectrum; the other colors have been harder to produce, and optimal wavelengths for blue and green have not been available. Large, outdoor color displays can benefit from bright, long-lived, and inexpensive blue and green LEDs. Having red, blue, and green enables LEDs to display all colors, making them useful for advertising, entertainment, and road signs. Optoelectronic managers estimate that the total market for full-color devices may exceed $20 billion annually in the next few years.

Through a BMDO IS&T contract, North Carolina State University, or NCSU (Raleigh, NC) developed a set of coating technologies for compound semiconductors based on homoepitaxial molecular beam epitaxy (MBE). NCSU used MBE to produce crystalline zinc selenide (ZnSe) thin films, which can be used to make LEDs. The university has licensed the technology to Eagle-Picher (Miami, OK), which has wide experience in the growth of bulk ZnSe. As a result of this partnership, Eagle-Picher is now using NCSU's MBE technology in a $1.75 million award from the National Institute of Standards & Technology Advanced Technology Program for work on blue and green LEDs and lasers. Eagle-Picher plans to manufacture some blue and green LEDs for niche markets. These LEDs have also generated considerable interest from other LED manufacturers.

THANKS TO THIS INDUSTRY/UNIVERSITY PARTNERSHIP, EAGLE-PICHER PLANS TO MANUFACTURE BLUE AND GREEN LEDs FOR NICHE MARKETS.

Blue LEDs are expected to replace red LEDs for applications beyond full-color displays. For example, bright, inexpensive, and long-lived blue and green LEDs could improve the resolution of laser printers. And, on a cybernetic note, blue lasers and LEDs will be useful in advanced computers and networks, which are likely to use optical data storage. These shorter wavelengths offer higher focusing properties and greater inherent information content for optical disks so they can extend their data storage capacity. Blue LEDs also can be used in environmental applications for pollution monitors and in transportation applications for aircraft cockpit displays and automotive instrumentation displays.

Pictured above is a collection of NCSU/Eagle-Picher substrates for blue and green LEDs.

About The Technology

These devices are based on compound semiconductor materials composed of precise atomic fractions of type II and type VI elements on the periodic table. Through NCSU's BMDO-funded R&D, Eagle-Picher has developed a bright green LED based on II-VI double heterostructures, such as zinc tellurium selenide (ZnTeSe), grown via homoepitaxial MBE. MBE uses chemical evaporation to grow thin crystalline films with doping profiles that can be carefully controlled. The green LEDs are the brightest green ever reported for a semiconductor material—at least 50 times brighter than commercial gallium phosphide LEDs. They emit light peaked at 512 nanometers and have been shown to operate reliably for up to 675 hours at a current density of 50 amperes per square centimeter.

NCSU and Eagle-Picher have also developed a blue LED with a crystalline structure similar to the green LED; the difference is in the "active region," which is zinc cadmium selenide instead of ZnTeSe. The blue LED's output is in the microwatt range, compared with that of the brighter green LED, which is in the milliwatt range. However, this LED has generated great excitement because its output is 30 times greater than that of the original blue silicon carbide LEDs. In fact, it produces the brightest blue ever made from II-VI structures.

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